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(54) **OPEN MAGNET WITH FLOOR MOUNT**

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(58) **Field of Search** 335/216, 299–301; 324/318–321; 505/883

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(57) **ABSTRACT**

A vertically-aligned open magnet includes first and second (i.e., top and bottom) assemblies each having a longitudinally-extending and vertically-aligned axis, a superconductive main coil, and a vacuum enclosure enclosing the main coil. At least one support beam has a first end attached to the first assembly and has a second end attached to the second assembly. An annularly-cylindrical support skirt is coaxially aligned with the axes, has a first longitudinal end attached to the second assembly and has a second longitudinal end supportable by a floor.

20 Claims, 2 Drawing Sheets

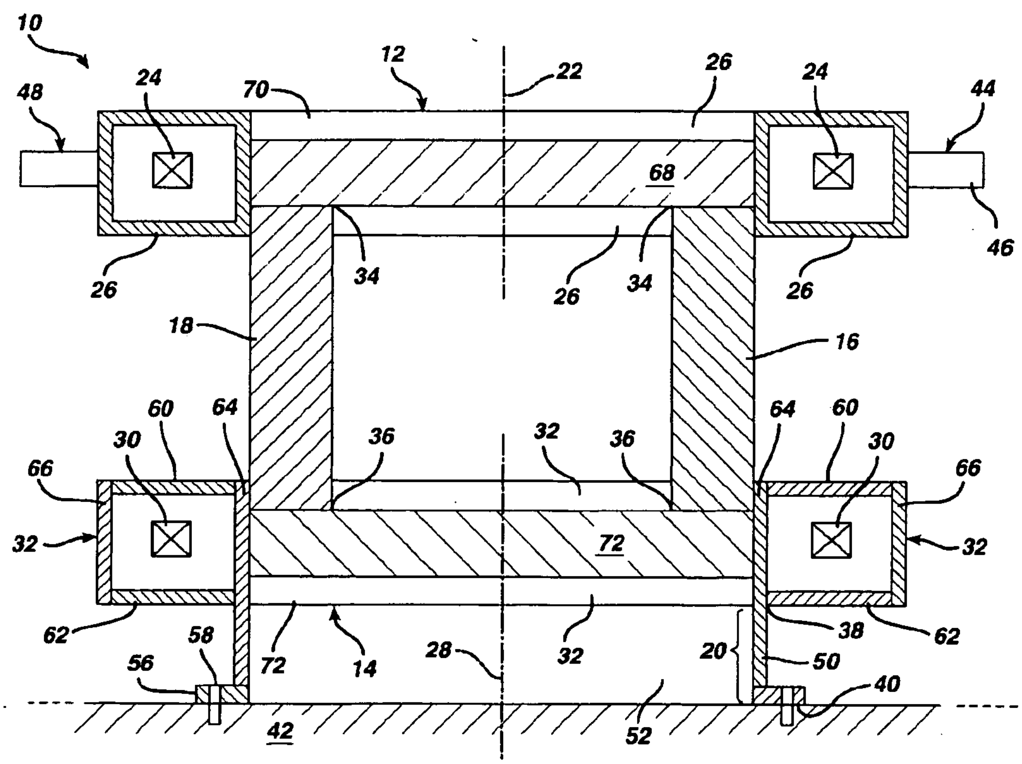


FIG. 1

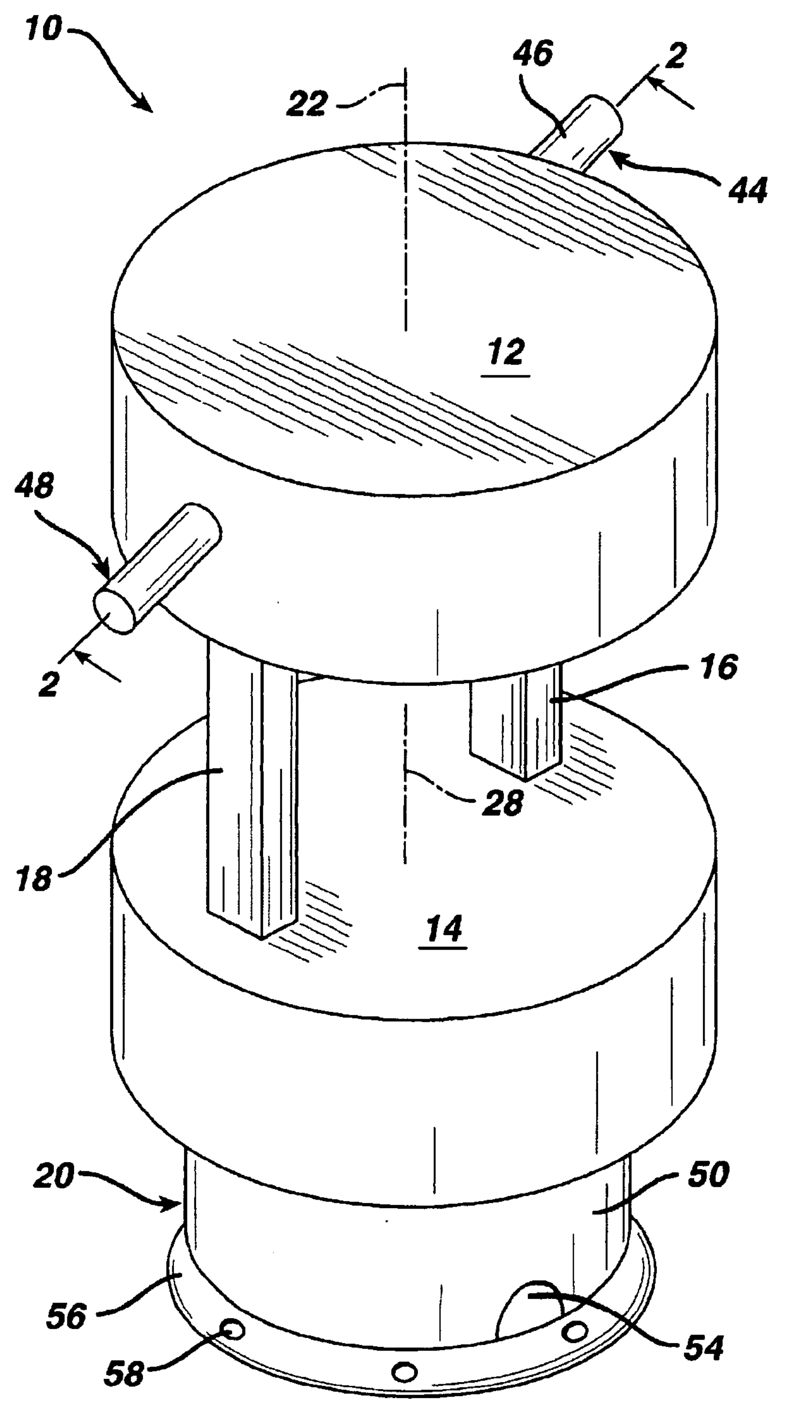
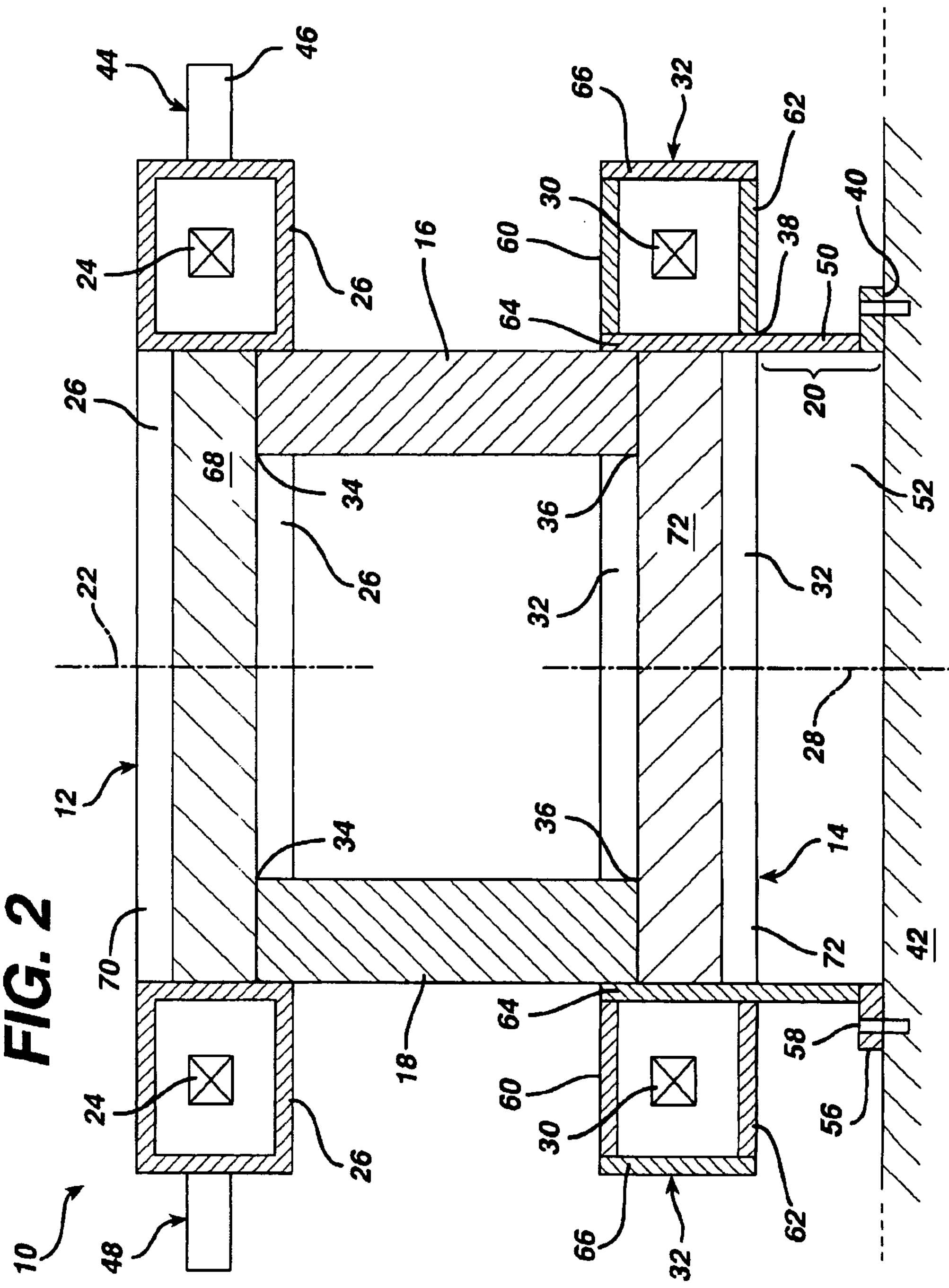


FIG. 2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OPEN MAGNET WITH FLOOR MOUNT

BACKGROUND OF THE INVENTION

The present invention relates generally to open magnets, and more particularly to an open magnet having a floor mount.

Magnets include resistive and superconductive magnets which are part of a magnetic resonance imaging (MRI) system used in various applications such as medical diagnostics. Known superconductive magnets include liquid-helium-cooled, cryocooler-cooled, and hybrid-cooled superconductive magnets. Typically, the superconductive coil assembly includes a superconductive main coil surrounded by a thermal shield surrounded by a vacuum enclosure. A cryocooler-cooled magnet typically also includes a cryocooler coldhead externally mounted to the vacuum enclosure, having its first stage in solid conduction thermal contact with the thermal shield, and having its second stage in solid conduction thermal contact with the superconductive main coil. A liquid-helium-cooled magnet typically also includes a liquid-helium vessel surrounding the superconductive main coil with the thermal shield surrounding the liquid-helium vessel. A hybrid-cooled magnet uses both liquid helium (or other liquid or gaseous cryogen) and a cryocooler coldhead, and includes designs wherein the first stage of the cryocooler coldhead is in solid conduction thermal contact with the thermal shield and wherein the second stage of the cryocooler coldhead penetrates the liquid-helium vessel to recondense "boiled-off" helium.

Known resistive and superconductive magnet designs include closed magnets and open magnets. Closed magnets typically have a single, tubular-shaped resistive or superconductive coil assembly having a bore. The coil assembly includes several radially-aligned and longitudinally spaced-apart resistive or superconductive main coils each carrying a large, identical electric current in the same direction. The main coils are thus designed to create a magnetic field of high uniformity within a typically spherical imaging volume centered within the magnet's bore where the object to be imaged is placed.

Open magnets, including "C" shape and support-post magnets, typically employ two spaced-apart coil assemblies with the space between the assemblies containing the imaging volume and allowing for access by medical personnel for surgery or other medical procedures during magnetic resonance imaging. The patient may be positioned in that space or also in the bore of the toroidal-shaped coil assemblies. The open space helps the patient overcome any feelings of claustrophobia that may be experienced in a closed magnet design.

It is also known in open magnet designs to place an iron pole piece in the bore of a resistive or superconductive coil assembly. The iron pole piece enhances the strength of the magnetic field and, by shaping the surface of the pole piece, magnetically shims the magnet improving the homogeneity of the magnetic field. Nonmagnetizable support posts are connected to the face of the pole pieces. It is additionally known in horizontally-aligned open magnets to support the magnet on the floor using two spaced-apart feet attached to each assembly, such feet raising the assemblies to provide room underneath the assemblies for necessary wires, pipes, etc.

The sharpness of an MRI image depends, in part, on the magnetic field in the imaging volume being time-constant and highly uniform, such magnetic field suffering time and spatial deformation caused by vibrations, especially vibrations imparted to the coil assemblies of an open magnet by the presence of a cryocooler coldhead. What is needed is a design for a superconductive open magnet which reduces vibrations and hence which improves the sharpness of an MRI image.

BRIEF SUMMARY OF THE INVENTION

In a first expression of an embodiment of the invention, a open magnet includes first and second assemblies, at least one support beam, and a support skirt. Each assembly includes a longitudinally-extending axis, at least one superconductive main coil generally coaxially aligned with the axis, and a vacuum enclosure enclosing the assembly's at least one main coil. The first axis of the first assembly is generally vertically aligned, the second assembly is positioned generally vertically below the first assembly, and the second axis of the second assembly is generally coaxially aligned with the first axis. The at least one support beam has a first end attached to the first assembly and has a second end attached to the second assembly. The support skirt is a generally longitudinally-extending, annularly-cylindrical support skirt which is generally coaxially aligned with the second axis, which has a first longitudinal end attached to the second assembly, and which has a second longitudinal end which can be supported by a floor. In one example, the open magnet also includes a first cryocooler coldhead having a first housing attached to one of the first and second vacuum enclosures.

In a second expression of an embodiment of the invention, an open magnet includes first and second assemblies, nonmagnetizable first and second support beams, and a support skirt. Each assembly includes a longitudinally-extending axis, at least one superconductive main coil generally coaxially aligned with the axis, a vacuum enclosure enclosing the assembly's at least one main coil and surrounding a bore, and a magnet pole piece. The magnet pole piece is located inside the bore and outside the vacuum enclosure and is attached to the vacuum enclosure. The first axis of the first assembly is generally vertically aligned, the second assembly is positioned generally vertically below the first assembly, and the second axis of the second assembly is generally coaxially aligned with the first axis. The first and second support beams each are generally vertically aligned, each have a first longitudinal end attached to the first magnet pole piece of the first assembly, and each have a second longitudinal end attached to the second magnet pole piece of the second assembly. The support skirt is a generally longitudinally-extending, annularly-cylindrical support skirt which is generally coaxially aligned with the second axis, which has a first longitudinal end attached to the second assembly, and which has a second longitudinal end which can be supported by a floor. In one example, the open magnet also includes a first cryocooler coldhead having a first housing attached to the first vacuum enclosure.

Several benefits and advantages are derived from the invention. Engineering analysis shows that, compared to using conventional feet found on horizontally-aligned open magnets, the support-skirt design for a vertically-aligned open magnet stiffens the support of the magnet thereby shifting the natural frequency of the open magnet to a higher value which reduces the susceptibility of the open magnet to vibrate at the dominant low-excitation-frequencies imparted to the magnet by the presence of a cryocooler coldhead attached to an assembly (such as attached to a pole piece of an assembly). Applicants found that cryocooler vibrations cause vibration of the superconductive main coils, cause unwanted eddy-currents generated by vibrations of the ther-

mal shields, and cause unwanted movement of the superconductive coils relative to the pole pieces all contributing to MRI image degradation. It is noted that, in a vertically-aligned open magnet, when the support member(s) provide a "clam-shell" support for the assemblies, the superconductive coils of such assemblies are subject to significant vibration from the cryocooler coldhead(s). It is further noted that a "clam-shell" support is provided by having only two support members, especially when the two support members are not diametrically aligned. Such clam-shell support is a very open support providing ease of patient table access to the imaging volume and providing ease of patient positioning within the imaging volume. Engineering analysis shows the support-skirt design of the invention reduces magnet vibrations in a vertically-aligned open magnet having a "clam-shell" support for the assemblies, especially for vibrations caused by the presence of a cryocooler coldhead.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic perspective view of an embodiment of an open magnet of the invention; and

FIG. 2 is a cross-sectional view of the open magnet of FIG. 1 taken along lines 2—2 of FIG. 1 wherein the cryocooler coldheads are shown without hatching for clarity.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, wherein like numerals represent like elements throughout, FIGS. 1–2 show an embodiment of the present invention. In a first expression of the embodiment of FIGS. 1–2 of the invention, an open magnet **10** includes a first assembly **12**, a second assembly **14**, at least one support beam **16** and **18**, and a support skirt **20**. The first assembly 12 has a longitudinally-extending and generally-vertically-aligned first axis **22**, at least one superconductive main coil **24**, and a first vacuum enclosure **26**. By "generally-vertically-aligned" is meant vertically aligned plus or minus twenty degrees. The at least one superconductive main coil **24** of the first assembly **12** is generally coaxially aligned with the first axis **22** and carries a first main electric current in a first direction. The first direction is defined to be either a clockwise or a counterclockwise circumferential direction about the first axis **22** with any slight longitudinal component of current direction being ignored. The first vacuum enclosure **26** encloses the at least one superconductive main coil **24** of the first assembly **12**. The second assembly **14** is longitudinally spaced apart from and disposed generally vertically below the first assembly **12**. The second assembly **14** has a longitudinally-extending second axis **28**, at least one superconductive main coil **30**, and a second vacuum enclosure **32**. The second axis **28** is generally coaxially aligned with the first axis **22**. The at least one superconductive main coil **30** of the second assembly **14** is generally coaxially aligned with the second axis **28** and carries a second main electric current in the previously-described first direction. The second vacuum enclosure **32** encloses the at least one superconductive main coil **30** of the second assembly **14**. The at least one support beam **16** and **18** has a first end **34** attached to the first assembly **12** and has a second end **36** attached to the second assembly **14**. The support skirt **20** is a generally longitudinally-extending, annularly-cylindrical support skirt which is generally coaxially aligned with the second axis **28**, which has a first longitudinal end **38** attached to the second assembly **14**, and which has a second longitudinal end **40** supportable by a floor **42**.

In one design, the open magnet **10** includes a first cryocooler coldhead **44** having a first housing **46** attached to one of the first and second vacuum enclosures **26** and **32**. The first housing **46** is shown as horizontally-aligned and rigidly attached to the first vacuum enclosure **26** in the figures, but in another application (not shown) the first cryocooler is attached to the first vacuum enclosure by a flexible bellows attachment and receives total weight-bearing support from a separate and rigid support ceiling or floor mount, such attachments reducing cryocooler-induced vibration. Although omitted from the figures for clarity, typically the first cryocooler coldhead **44** includes first and second stages. The second stage is in solid conduction thermal contact with the at least one superconductive main coil, or the second stage acts as a recondenser of boiled-off liquid helium contained in a cryogenic vessel. The first stage is in solid conduction thermal contact with a thermal shield which generally surrounds the at least one superconductive main coil or which generally surrounds the cryogenic vessel containing the at least one superconductive main coil and which is itself surrounded by the first vacuum enclosure. In the application shown in the figures, there is added a second cryocooler coldhead **48** which is a single-stage cryocooler coldhead whose first stage (omitted from the figures for clarity) is in solid conduction thermal contact with the thermal shield of the first assembly. Here, the at least one superconductive main coil of the first assembly would be thermally connected to the at least one superconductive main coil of the second assembly, as can be appreciated by those skilled in the art.

In one example, the support skirt **20** provides the only weight-bearing support for the second assembly **14**. In this example, the support skirt **20** has an annularly-cylindrical wall **50** surrounding an interior space **52**, and the annularly-cylindrical wall **50** has at least one opening **54** allowing access to the interior space **52** for necessary wires, pipes, etc., as can be appreciated by the artisan. It is noted that although the annularly-cylindrical wall **50** has at least one opening **54**, to maintain structural integrity to support the weight of the open magnet **10**, the annularly-cylindrical wall **50** is never longitudinally split apart. Here, the support skirt **20** proximate its second longitudinal end **40** has a radially-outwardly-extending flange **56** having a plurality of generally vertically-extending bolt holes **58**. Bolts (not shown in the figures) would attach the flange **56** to the floor **42** or to a plate or other structure resting on the floor.

In one construction, the second vacuum enclosure **32** has generally horizontally-aligned and generally planar and annular-shaped first and second walls **60** and **62** generally coaxially aligned with the second axis **28**. The second vacuum enclosure **32** also has circumferentially-extending third and fourth walls **64** and **66**. The first wall **60** is spaced apart from and disposed vertically above the second wall **62**. The third wall **64** is spaced apart from and disposed radially inward from the fourth wall **66**. The third and fourth walls **64** and **66** are each hermetically attached to both the first and second walls **60** and **62**. In one design, the third wall **64** monolithically extends vertically below the second wall **62**, and the third wall **64** vertically below the second wall **62** defines the annularly-cylindrical wall **50** of the support skirt **20**.

In one application, the at least one support beam **16** and **18** is radially disposed proximate the support skirt **20**. One type of "clam-shell" support for the first and second assemblies 12 and 14 is provided when the at least one support beam **16** and **18** consists of diametrically-offset first and second support beams **16** and **18**. In one example, the first

and second support beams **16** and **18** are radially disposed between generally 110 and 150 degrees apart.

In a second expression of the embodiment of FIGS. **1–2** of the invention, an open magnet **10** includes a first assembly **12**, a second assembly **14**, nonmagnetizable first and second support beams **16** and **18**, and a support skirt **20**. A support member is said to be a nonmagnetizable support member if it includes at least a nonmagnetizable portion which blocks having a magnetizable path between its ends. Such nonmagnetizable portion would have a relative permeability of generally unity. Examples of nonmagnetizable materials include aluminum, copper, nonmagnetic stainless steel, plastic, wood, etc. The first assembly **12** has a longitudinally-extending and generally-vertically-aligned first axis **22**, at least one superconductive main coil **24**, a first vacuum enclosure **26**, and a first magnet pole piece **68**. The at least one superconductive main coil **24** of the first assembly **12** is generally coaxially aligned with the first axis **22** and carries a first main electric current in a first direction. The first vacuum enclosure **26** encloses the at least one superconductive main coil **24** of the first assembly **12** and surrounds a first bore **70**. The first magnet pole piece **68** is generally coaxially aligned with the first axis **22**, is disposed inside the first bore **70** and outside the first vacuum enclosure **26**, and is attached to the first vacuum enclosure **26**. The second assembly **14** is longitudinally spaced apart from and disposed generally vertically below the first assembly **12**. The second assembly **14** has a longitudinally-extending second axis **28**, at least one superconductive main coil **30**, a second vacuum enclosure **32**, and a second magnet pole piece **72**. The second axis **28** is generally coaxially aligned with the first axis **22**. The at least one superconductive main coil **30** of the second assembly **14** is generally coaxially aligned with the second axis **28** and carries a second main electric current in the previously-described first direction. The second vacuum enclosure **32** encloses the at least one superconductive main coil **30** of the second assembly **14** and surrounds a second bore **74**. The second magnet pole piece **72** is generally coaxially aligned with the second axis **28**, is disposed inside the second bore **74** and outside the second vacuum enclosure **32**, and is attached to the second vacuum enclosure **32** The first and second support beams **16** and **18** each are generally vertically aligned, each have a first end **34** attached to the first assembly **12** and each have a second end **36** attached to the second assembly **14**. The support skirt **20** is a generally longitudinally-extending, annularly-cylindrical support skirt which is generally coaxially aligned with the second axis **28**, which has a first longitudinal end **38** attached to the second assembly **14**, and which has a second longitudinal end **40** supportable by a floor **42**.

Options for the second expression of an embodiment of the open magnet **10** of the invention are the same as the optional designs, examples, constructions, and applications previously-described for the first expression of an embodiment of the open magnet **10** of the invention with differences hereinafter noted. In one design of the second expression of an embodiment of the open magnet **10** of the invention, the first cryocooler coldhead **44** has a first housing **46** which is attached to the first vacuum enclosure **26**. In one example of the second expression of an embodiment of the open magnet **10** of the invention, the flange **56** of the support skirt **20** is attached (such as by welding) to the annularly-cylindrical wall **50** of the support skirt **20**. In one construction, engineering calculations show an open magnet **10** weighing generally 18,000 pounds can have its second assembly **14** supported by a support skirt **20** wherein the third wall **64** of the second vacuum enclosure **32** (which below the second wall **62** defines the annularly-cylindrical wall **50** of the support skirt **20**) comprises nonmagnetic stainless steel having a diameter of generally four feet and having a plate thickness of generally 0.25 to 0.50 inch with the first, second, and fourth walls requiring a thickness of generally 0.20 inch. It is noted that the stiffness of the first and second support beams **16** and **18** and the stiffness of the support skirt **20** can be chosen by those skilled in the art to reduce magnet vibration, such as cryocooler-imparted vibration, while providing structural support against gravitational and electromagnetic forces.

Several benefits and advantages are derived from the invention. Engineering analysis shows that, compared to using conventional feet found on horizontally-aligned open magnets, the support-skirt design for a vertically-aligned open magnet stiffens the support of the magnet thereby shifting the natural frequency of the open magnet to a higher value which reduces the susceptibility of the open magnet to vibrate at the dominant low-excitation-frequencies imparted to the magnet by the presence of a cryocooler coldhead attached to an assembly (such as attached to a pole piece of an assembly). Applicants found that cryocooler vibrations cause vibration of the superconductive main coils, cause unwanted eddy-currents generated by vibrations of the thermal shields, and cause unwanted movement of the superconductive coils relative to the pole pieces all contributing to MRI image degradation (including "ghosting" in images). It is noted that, in a vertically-aligned open magnet, when the support member(s) provide a "clam-shell" support for the assemblies, the superconductive coils of such assemblies are subject to significant vibration from the cryocooler coldhead(s). It is further noted that a "clam-shell" support is provided by having only two support members, especially when the two support members are not diametrically aligned. Such clam-shell support is a very open support providing ease of patient table access to the imaging volume and providing ease of patient positioning within the imaging volume. Engineering analysis shows the support-skirt design of the invention reduces magnet vibrations in a vertically-aligned open magnet having a "clam-shell" support for the assemblies, especially for vibrations caused by the presence of a cryocooler coldhead.

It should be noted that additional superconductive main coils, superconductive shielding coils, superconductive correction coils, and magnetizable rings may be present, as is known to the artisan, but such coils and rings have been omitted from the figures for clarity. Likewise, coil forms (if needed) to support the superconductive main coils and spacers to position a thermal shield with respect to a cryogenic vessel and to position a thermal shield with respect to a vacuum enclosure have been omitted from the figures but are well known to those skilled in the art. In an example, the open magnet **10** is a 0.5 or higher Tesla magnet, and the cryocooler coldheads are Gifford McMahon cryocooler coldheads.

The foregoing description of several expressions of an embodiment of the invention has been presented for purposes of illustration. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and obviously many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be defined by the claims appended hereto.

What is claimed is:

1. An open magnet comprising:

a) a first assembly including:

(1) a longitudinally-extending and generally-vertically-aligned first axis;

(2) at least one superconductive main coil positioned around said first axis and carrying a first main electric current in a first direction; and

(3) a first vacuum enclosure enclosing said at least one superconductive main coil of said first assembly;

b) a second assembly longitudinally spaced apart from and disposed below said first assembly and including:

(1) a longitudinally-extending second axis generally coaxially aligned with said first axis;

(2) at least one superconductive main coil positioned around said second axis and carrying a second main electric current in said first direction; and

(3) a second vacuum enclosure enclosing said at least one superconductive main coil of second assembly;

c) at least one support beam external to said first and second vacuum enclosure having a first end attached to said first assembly and having a second end attached to said second assembly;

d) a longitudinally-extending, annularly-cylindrical support skirt positioned around said second axis, having a first longitudinal end attached to and external to said second assembly, and having a second longitudinal end supportable by a floor.

2. The open magnet of claim **1**, also including a first cryocooler coldhead having a first housing attached to one of said first and second vacuum enclosures.

3. The open magnet of claim **1** wherein said support skirt is attached to the exterior of said second assembly and is the weight-bearing support for said second assembly.

4. The open magnet of claim **1**, wherein said support skirt has an annularly-cylindrical wall surrounding an interior space, and wherein said annularly-cylindrical wall has at least one opening allowing access to said interior space.

5. The open magnet of claim **4**, wherein said support skirt at its second longitudinal end has a radially-outwardly-extending flange having a plurality of generally vertically-extending bolt holes.

6. An open magnet comprising:

a) a first assembly including:

(1) a longitudinally-extending and generally-vertically-aligned first axis;

(2) at least one superconductive main coil positioned around said first axis and carrying a first main electric current in a first direction; and

(3) a first vacuum enclosure enclosing said at least one superconductive main coil of said first assembly;

b) a second assembly longitudinally spaced apart from and disposed generally vertically below said first assembly and including:

(1) a longitudinally-extending second axis positioned around said first axis;

(2) at least one superconductive main coil positioned around said second axis and carrying a second main electric current in said first direction; and

(3) a second vacuum enclosure enclosing said at least one superconductive main coil of second assembly;

c) at least one support beam having a first end attached to said first assembly and having a second end attached to said second assembly;

d) a longitudinally-extending, annularly-cylindrical support skirt generally-coaxially-aligned with said second axis, having a first longitudinal end attached to said second assembly, and having a second longitudinal end supportable by a floor;

wherein said support skirt has an annularly-cylindrical wall surrounding an interior space, and wherein said annularly-cylindrical wall has at least one opening allowing access to said interior space;

wherein said support skirt at its second longitudinal end has a radially-outwardly-extending flange having a plurality of generally vertically-extending bolt holes; and

wherein said second vacuum enclosure has horizontally-aligned and planar and annular-shaped first and second walls generally coaxially aligned with said second axis and has circumferentially-extending third and fourth walls, wherein said first wall is spaced apart from and disposed vertically above said second wall, wherein said third wall is spaced apart from and disposed radially inward from said fourth wall, and wherein said third and fourth walls are each hermetically attached to both said first and second walls.

7. The open magnet of claim **6**, wherein said third wall monolithically extends vertically below said second wall, and wherein said third wall vertically below said second wall defines said annularly-cylindrical wall of said support skirt.

8. The open magnet of claim **1**, wherein said at least one support beam is radially disposed contiguous to said support skirt.

9. The open magnet of claim **8**, wherein said at least one support beam consists of diametrically-offset first and second support beams.

10. The open magnet of claim **9**, wherein said first and second support beams are radially disposed between 110 and 150 degrees apart.

11. An open magnet comprising:

a) a first assembly including:

(1) a longitudinally-extending and vertical first axis;

(2) at least one superconductive main coil positioned around said first axis and carrying a first main electric current in a first direction;

(3) a first vacuum enclosure enclosing said at least one superconductive main coil of said first assembly and surrounding a first bore; and

(4) a first magnet pole piece generally coaxially aligned with said first axis, disposed inside said first bore and outside said first vacuum enclosure, and attached to said first vacuum enclosure;

b) a second assembly longitudinally spaced apart from and vertically below said first assembly and including:

(1) a longitudinally-extending second axis generally coaxially aligned with said first axis;

(2) at least one superconductive main coil positioned around said second axis and carrying a second main electric current in said first direction;

(3) a second vacuum enclosure enclosing said at least one superconductive main coil of said second assembly and surrounding a second bore; and

(4) a second magnet pole piece generally coaxially aligned with said second axis, disposed inside said second bore and outside said second vacuum enclosure, and attached to said second vacuum enclosure;

c) nonmagnetizable first and second support beams external to said first and second vacuum enclosure each generally-vertically-aligned, each having a first longitudinal end attached to said first magnet pole piece, and each having a second longitudinal end attached to said second magnet pole piece; and

d) a longitudinally-extending, annularly-cylindrical support skirt positioned around said second axis, having a

first longitudinal end attached to and external to said second assembly, and having a second longitudinal end supportable by a floor.

12. The open magnet of claim 11, also including a first cryocooler coldhead having a first housing attached to said first vacuum enclosure.

13. The open magnet of claim 12 wherein said support skirt is attached to the exterior of said second assembly and is the weight-bearing support for said second assembly.

14. The open magnet of claim 13, wherein said support skirt has an annularly-cylindrical wall surrounding an interior space, and wherein said annularly-cylindrical wall has at least one opening allowing access to said interior space.

15. The open magnet of claim 14, wherein said support skirt at its second longitudinal end has a radially-outwardly-extending flange having a plurality of generally vertically-extending bolt holes.

16. An open magnet comprising:

a) a first assembly including:
   (1) a longitudinally-extending and generally-vertically-aligned first axis;
   (2) at least one superconductive main coil positioned around said first axis and carrying a first main electric current in a first direction;
   (3) a first vacuum enclosure enclosing said at least one superconductive main coil of said first assembly and surrounding a first bore; and
   (4) a first magnet pole piece positioned around said first axis, disposed inside said first bore and outside said first vacuum enclosure, and attached to said first vacuum enclosure;

b) a second assembly longitudinally spaced apart from and disposed below said first assembly and including:
   (1) a longitudinally-extending second axis generally coaxially aligned with said first axis;
   (2) at least one superconductive main coil positioned around said second axis and carrying a second main electric current in said first direction;
   (3) a second vacuum enclosure enclosing said at least one superconductive main coil of said second assembly and surrounding a second bore; and
   (4) a second magnet pole piece positioned around said second axis, disposed inside said second bore and outside said second vacuum enclosure, and attached to said second vacuum enclosure;

c) nonmagnetizable first and second support beams each generally-vertically-aligned, each having a first longitudinal end attached to said first magnet pole piece, and each having a second longitudinal end attached to said second magnet pole piece;

d) a longitudinal, annularly-cylindrical support skirt positioned around said second axis, having a first longitudinal end attached to said second assembly, and having a second longitudinal end supportable by a floor;

also including a first cryocooler coldhead having a first housing attached to said first vacuum enclosure;

wherein said support skirt supports said assembly;

wherein said support skirt has an annularly-cylindrical wall surrounding an interior space, and wherein said annularly-cylindrical wall has at least one opening allowing access to said interior space;

wherein said support skirt proximate its second longitudinal end has a radially-outwardly-extending flange having a plurality of vertically-extending bolt holes; and

wherein said second vacuum enclosure has a horizontal disk shape and annularly-shaped first and second walls positioned around said second axis and has circumferentially-extending third and fourth walls, wherein said first walls is spaced apart from and disposed vertically above said second wall, wherein said third wall is spaced apart from and disposed radially inward from said fourth wall, and wherein said third and fourth walls are each hermetically attached to both said first and second walls.

17. The open magnet of claim 16, wherein said third wall monolithically extends vertically below said second wall, wherein said third wall vertically below said second wall defines said annularly-cylindrical wall of said support skirt, and wherein said flange of said support skirt is attached to said annularly-cylindrical wall of said support skirt.

18. The open magnet of claim 17, wherein said at least one support beam is radially disposed contiguous to said support skirt.

19. The open magnet of claim 18, wherein said at least one support beam consists of diametrically-offset first and second support beams.

20. The open magnet of claim 19, wherein said first and second support beams are radially disposed between generally 110 and 150 degrees apart.

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